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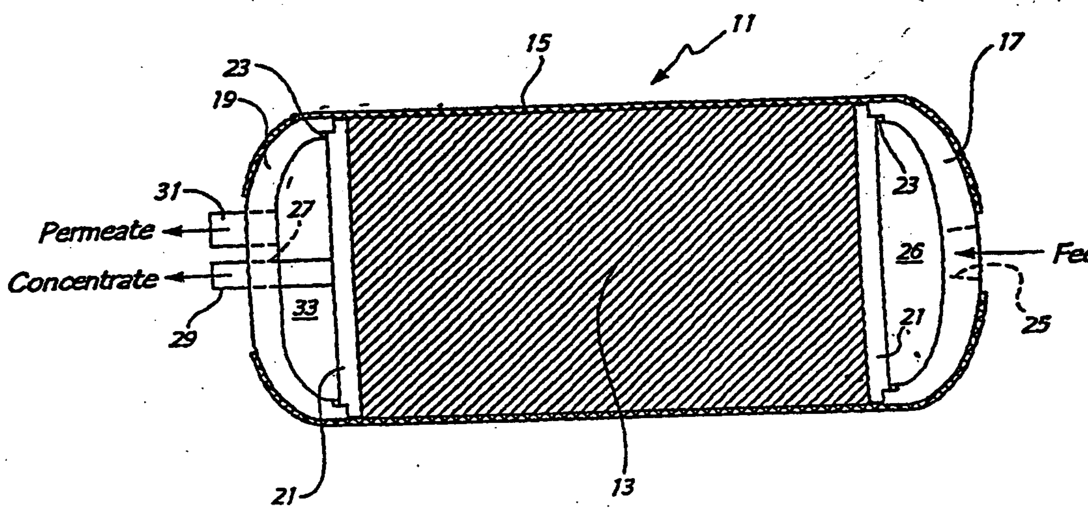

(57) Abstract

Spirally wound separation devices utilize alternating leaves of carrier material and envelopes of MF, UF, NF or RO membranes which sandwich a permeate sheet. Each envelope is sealed along three edges with one longitudinal edge being open. At the feed axial end of the spirally wound element, there is an annular open region which surrounds the central region of spirally wound leaves, through which annular region the feed liquid is supplied. At the exit axial end, only the now spiral edge of each envelope is open, which provides a very short flow path for the permeate to travel prior to exit from the element. The liquid concentrate exits through a central porous tube. Self-contained separation devices are created by associating dome-shaped heads with each end of such a cylindrical element and then helically and polarly wrapping fibrous material, containing long strands of synthetic fibers, impregnated with polymeric resin repeatedly about the cylindrical surface and the two dome-shaped ends in order to, upon curing of the resin, create a pressure vessel of adequate strength. The device is economic to manufacture and is capable of providing high flow, high recovery filtration treatment of liquids.

HIGH FLOW HIGH RECOVERY SPIRALLY WOUND FILTRATION ELEMENT

Field of Invention

This invention relates to spirally wound separation devices and particularly to such devices used in crossflow liquid separation processes, such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. More particularly, this invention relates to spirally wound filtration cartridge construction using membranes of known character to separate an impure liquid feed stream into a pure permeate stream and a concentrate stream. The membranes may be microfiltration (MF) membranes, ultrafiltration (UF) membranes; nanofiltration (NF) membranes or reverse-osmosis (RO) membranes, which are frequently referred to as semipermeable membranes; however, the invention is felt to be particularly useful for devices employing microfiltration membranes which are capable of high flow and high percentage recovery at relatively low operating pressure.

Background of the Invention

The term "semipermeable membrane" implies that certain materials can pass through the microporous membrane, while others cannot, i.e. they permit permeation flow of solvent and some solutes while rejecting passage of other solutes and suspended solids. These membranes are generally classified by the particle sizes of the materials which are retained by the membranes while passing a fluid through them. Particles having a mean diameter greater than about 1 micron can be separated from a liquid carrier using gravity filtration through ordinary filter paper. At the other extreme, certain solute particles smaller than about 10^{-3} microns, i.e., about 1-10 Angstroms (the size of simple anions and cations) can be separated from a liquid by reverse osmosis. Ultrafiltration generally separates particles larger than about 10^{-2} microns, whereas nanofiltration separates solute particles ranging from about 10^{-3} to 10^{-2} microns in size, i.e., particles in a size range between those separable by RO and UF. The present invention may be particularly useful with microfiltration membranes and processes, which remove particles in the size range of about 0.1 micron and above.

Crossflow membrane separation devices frequently utilize cartridges or elements wherein an arrangement of feed spacer sheets, membranes and permeate carrier sheets are spirally wound about a central porous or perforated tube to create a cylindrical

structure that is adapted for use within a tubular pressure vessel of circular cross-section, through which the feed liquid being treated will be caused to axially flow, with a concentrate stream usually exiting one axial end. Early elements of this type are shown in U.S. Patent No. 3,417,870, and more recent versions are shown in U.S. Patent Nos. 4,517,085, 4,548,714 and 5,128,037. These patents variously show the association of anti-telescoping devices (ATDs) with each axial end of the spirally wound element or cartridge and optionally disposing a plurality of such cartridges in series arrangement within a single tubular pressure vessel. In addition to the reverse osmosis, ultrafiltration or nanofiltration membranes that are disclosed in such patents, microfiltration membranes of the fluorocarbon type, such as those disclosed in U.S. Patent No. 5,032,274, have also been employed in such spirally wound cartridges.

In recent years, microfiltration and ultrafiltration membranes have begun to be used for many water purification applications wherein the desire is to remove finely suspended solids and biological components, such as bacteria, cryptosporidium, giardia, viruses and the like. The purpose of using such a microfilter is to provide an absolute barrier which will prevent contamination of a potable water supply, e.g., as a final treatment for water exiting from a municipal water supply plant. However, devices of this type are not so limited in their use; they may also be used to remove contaminants from highly fouling waters, such as the effluent from tertiary treatment of waste water. Because RO membranes are rather susceptible to serious fouling and because microfiltration membranes can be chemically cleaned with chlorine and generally quite effectively backwashed, equipment employing microfiltration membranes and/or ultrafiltration membranes is also considered particularly useful for pretreatment prior to certain separation processes using reverse-osmosis membranes, e.g. when the product being produced is so-called grey water intended for distribution and subsequent use.

Overall, such operations usually involve the treatment of relatively large volumes of water and require the membranes to be mechanically robust in order to avoid contamination of the product water as a result of membrane failure. Heretofore, hollow fiber membrane modules have fairly commonly been the choice for these types of applications, particularly because hollow fiber geometry minimizes the pressure drop for the permeate stream (thereby maximizing productivity) while also providing high membrane-packing densities and relative ease of backwashing. However, spiral-wound

membrane cartridges have heretofore proved versatile for a variety of applications in municipal water treatment and throughout the food and dairy industry, the pharmaceutical industries, waste water recycling and the like. Moreover, for such applications, in addition to the so-called standard spiral-wound separation devices, a number of modifications have been proposed for such cartridges.

U.S. Patent No. 4,033,878 discloses a cartridge arrangement where the fluid stream being treated first enters a porous hollow central tube and is then caused to flow along a serpentine path which is created in a carrier sheet disposed in an envelope between two sheets of semipermeable membrane, with the concentrate stream exiting through a discharge passageway at the other end of the central hollow tube which is blocked at a midway location. The exterior of the element is wrapped with nonpermeable plastic tape to appropriately size the element for installation in a tubular pressure vessel.

U.S. Patent No. 5,108,604 shows associating a spirally wound semipermeable membrane cartridge with a pair of pressure vessel end fittings in a mold into which a reaction molding compound is then injected. The result is a creation of a self-contained separation cartridge/ pressure vessel combination.

U.S. Patent No. 4,855,058 discloses a spirally wound membrane separation element of cylindrical shape wherein the feed is via a hollow axial tube, with the concentrate exiting at the outer end of a spiral flow path and the permeate exiting from one axial end of the spirally wound arrangement. U.S. Patent No. 5,266,195 is generally similar and discloses an arrangement where water enters a hollow center region 109 via a drilled hole 107 (FIG. 4) in an end plate and flows spirally outward in feed passageway material, while the permeating water flows spirally inward to an exit tube (93) provided in the central region.

Although various of these modified constructions have shown advantages for certain specific applications, none of them has experienced widespread acceptance in the marketplace. Therefore, the search has continued for improved constructions for spirally wound crossflow separation units, particularly for those adapted to high flow, high recovery microfiltration of liquids at relatively low pressure.

Summary of the Invention

In one aspect, the invention provides a spirally wound crossflow separation device utilizing a plurality of leaves which each include a permeate sheet sandwiched between two microporous membranes; these leaves are interleaved with feed/concentrate carrier sheets and then wound in a spiral configuration about a central porous tube to create a generally cylindrical element or cartridge. The membranes are preferably sheets of asymmetric microfiltration membrane that are capable of high flow at relatively low pressure differential. The membrane sheets are preferably folded about the permeate sheets to form elongated rectangular envelopes, which envelopes are open along one side edge. One axial end of the spirally wound cylindrical element is completely sealed in the region of the spirally wound leaves, as with cured polymeric resin, and at the opposite end, only the spiral side edge of each membrane envelope is open to provide an elongated exit for each permeate sheet. Through the provision of a surrounding annular region of open mesh material, feed liquid is efficiently directed to the outer end of each of the plurality of spirally wound feed/concentrate carrier sheets, and the concentrate stream is removed from the porous central tube about which the arrangement is spirally wound.

In a particularly preferred embodiment, such a spirally wound separation element arrangement is overwrapped with multiple layers of helically-applied polymer-impregnated fibrous material, and a pair of dome-shaped heads and preferably associate ATDs, are positioned at each axial end of the element and united thereto by integrated polar-wrappings of such polymer-impregnated fibrous material. Thereafter, following curing of the polymeric resin, a liquid-tight enclosure is created about the cylindrical separation element. The result is a self-contained separation element-pressure vessel device which is capable of adequately withstanding operating pressures up to about 200 psig or even higher. Thus, there is provided a relatively low cost device for high flow, high recovery treatment of feed liquid at moderate pressures which is particularly well-suited for microfiltration applications.

In another aspect, the invention provides a spirally wound separation device wherein leaves, in the form of envelopes of separation membranes that sandwich therebetween a permeate sheet are alternated with feed/concentrate carrier sheets and wound spirally about a central hollow porous tube. The envelopes are elongated, being

are closed along their spirally inner and outer edges and along one longitudinal edge, while the other longitudinal edge is left open to permit exit flow of permeate therefrom. Similarly elongated feed/carrier sheets are sealed along both their side edges to the adjacent edges of the envelopes, and an annular open mesh region is provided surrounding the spiral-wound arrangement to supply feed liquid to the open outer end of each of the feed/concentrate carrier sheets. A dome-shaped head is associated with each end of the element, and the entire assembly is united by wrapping with multiples plies of polymer-impregnated fibrous material containing long strands of synthetic fibers or the like. These wrappings are helically about the cylindrical body of the element and in polar fashion about each of the dome-shaped heads, which heads contain the necessary feed inlets and concentrate and permeate/filtrate outlets. Upon curing of the polymeric resin, a strong liquid-tight pressure vessel is integrally created about the separation element, providing a self-contained device which is capable of efficient operation at relatively low pressures to separate a feed liquid stream into a filtrate or permeate stream and a concentrate stream.

In a further aspect, the invention provides a method of making a separation device of the aforementioned type wherein one axial end of the spirally wound cylindrical element may be sealed by immersion into a bath of polymeric resin of desired viscosity which wicks into porous sheet material and, upon curing, blocks any liquid flow into or out of that end of the element except for the circumferential annular feed region which is kept open by imposing a gasket or the like that blocks entry of the resin. The other axial end may be similarly sealed using a polymeric resin having a viscosity such that it will wick substantially further into the interstices of the annular feed region and the feed/concentrate carrier sheets than into the permeate sheets; thereafter, trimming this axial end of the element so as to remove the region of polymeric intrusion into the permeate sheets opens the spiral edge of the permeate sheet winding while the adjacent spiral edges of the feed/concentrate carrier sheets remain sealed. By helically wrapping polymer-impregnated fabric strips or long tows of synthetic fibers, in multiple plies, about the cylindrical body and polarly about a pair of dome-shaped heads, a strong integral pressure vessel is created capable of operating under interior pressures as high as about 200 psig.

In a still further aspect, the invention provides a method of high flow, high recovery microfiltration of liquids by feeding a liquid stream to be treated into an annular region that surrounds a spirally wound microfiltration element which is encased within an integral pressure vessel formed *in situ* by wrapping polymer- impregnate fibrous material helically about such a spirally wound separation element and polarly about a pair of dome-shaped heads which, along with ATDs, are associated with the respective axial ends of the element. The use of multiple plies of polymer-impregnated fibrous material, upon curing, effectively create an integral pressure vessel that is capable of effectively withstanding pressures of about 200 psig. The filtrate or permeate stream need only traverse a very short path across the width of the permeate sheets to exit along an open spiral edge at one axial end of the element so that the overall arrangement provides for very efficient high flow, high recovery separation, particularly microfiltration, of aqueous feeds.

Brief Description of the Drawings

FIG. 1 is a schematic view of a self-contained separation device which includes a spirally wound separation element encased within an *in situ*-formed pressure vessel, illustrating the associated fittings for flow into and out of the device.

FIG. 2 is a schematic view illustrating the flow into and out of the ends of a spirally wound separation element of the type depicted in FIG. 1, without the association of the exterior pressure vessel.

FIG. 3 is a cross-sectional view taken generally along line 3-3 of FIG. 1 showing one axial end of the spirally wound separation element.

FIG. 4 is a schematic view illustrating one method of making such a spirally wound separation element together with indications of the flow patterns of liquid streams during operation of the element after it is rolled into its spirally wound condition.

FIG. 5 is a diagrammatic view of equipment that might be used for winding polymer-impregnated fibrous material helically about a spirally wound separation element to create an integral, liquid-tight exterior pressure vessel which encloses such separation element.

Detailed Description of Preferred Embodiments

As shown schematically in FIG. 1, the invention provides a separation device 11 which is particularly suited for microfiltration wherein a cylindrical, spirally wound separation element or cartridge 13 is encapsulated in an outer shell 15, which shell includes a pair of generally dome-shaped heads 17, 19. The heads are preferably of elliptical dome-shape and generally become an integral part of the outer shell 15 by forming a portion of the shell *in situ* thereabout, i.e., by wrapping polymer-impregnated fibrous material helically about the outer cylindrical surface and polarly about each of the dome-shaped heads.

Located between each of the heads and the spirally wound element is an ATD 21 of standard construction and a ring-type seal 23 of preferably square cross-section that is seated in an annular relief provided in the inner face of each head 17, 19. The right-hand head 17 contains a feed inlet 25 which may include pipe threads and is sometimes referred to as the feed head; its hollow interior serves as an entrance plenum 26. The left-hand head 19 carries the permeate and concentrate exits, and it is sometimes referred to as the exit head. It may be formed with a centrally located exit passageway through which both exit streams coaxially pass, or it may include separate outlets. The separation element is spirally wound about a tube 29 having the usual porous or perforated sidewall section, so that liquid can enter the tube in the region surrounded by the spiral wrapping, and an imperforate section which extends axially to the left, exiting the pressure vessel through a centrally located opening 27 and serving as the concentrate outlet. A separate permeate or filtrate outlet 31 is offset from the concentrate outlet 29 being suitably attached to the head 19. The interior region 33 provided by the exit head 19 serves as a plenum in the device 11 to collect the permeate or filtrate exiting from the one axial end of the spiral-wound element and direct it to the permeate outlet 31.

The operation of the spiral-wound element is shown schematically in FIGS. 2 and 4. As a part of its construction, there is an interleaving of composite leaves 45 and spacer or carrier sheets 47 that constitute a subassembly that is wrapped spirally around the tube 29. Surrounding the spirally wrapped leaves 45 and carrier sheets 47 is an annular region 35 of open mesh material which constitutes an annular circumferential portion of the spiral element. The cylindrical exterior of the element is helically wrapped with impermeable tape 37, as known in the art, to constitute the outer boundary of the

spiral-wound element and to restrain the leaves and carrier sheets in their spirally wound condition. As shown schematically in FIG. 2, the water or other liquid to be treated enters the annular open mesh region 35 via the plenum 26 at the feed or inlet end of the spirally wound element 13; the remainder of that axial end of the spirally wound element is sealed, as explained in more detail hereinafter. In addition, a plug 39 fills the end of the central tubular conduit 29, blocking any flow into or out of that end of the conduit. Thus, all the feed water to be treated entering through the feed inlet 25 of the inlet head 17 flows into the annular region of open mesh material 35 surrounding the spirally wrapped leaves and carrier sheets, as show schematically in FIG. 2 and hereinafter explained in detail.

The interleaved carrier sheets 47 serve as feed/concentrate flow passageways which extend for the entire length of each of the envelopes, and the outer ends of all of these carrier sheets are in liquid communication with annular outer region 35. In the preferred embodiment that is illustrated in FIG. 4, the carrier sheets 47 are longer than the leaves 45. Thus, each carrier sheet extends past the outer end of the adjacent leaf and the wound group of outer ends constitute the annular open mesh region 35. As the liquid feed flows spirally inward, a substantial percentage of it permeates through membrane sheets that form the outer boundaries of the leaves 45 and enters permeate sheets 51 (as best seen schematically in FIG. 4). The portion of the feed liquid that does not permeate through the membranes reaches the central conduit 29, the interior of which it enters through holes 49 in the porous sidewall and then exits as a concentrate stream via the open left-hand end of the tube 29. The arrangement is such that the liquid permeate or filtrate which passes through the membranes has only a short distance to flow to reach the open axial end of the spirally wound element, from which it exits, as shown diagrammatically by the arrows in FIG. 2.

More specifically, as seen in FIG. 3 and shown diagrammatically in FIG. 4, the spirally wound element 13 is fabricated by spirally rolling an assembly of alternating leaves 45 and carrier sheets 47 about a central tube 29 which has a main section that is porous, e.g. perforated with a plurality of holes 49 in its sidewall. The carrier sheets 47 are wrapped so as to touch the surface of the tube 29 so there is fluid communication from the flow passageways provided by the carrier sheets immediately surrounding the tube 29 and the tube interior. For example, as shown in FIG. 4, the tube

29 may be provided with one or more rows of spaced-apart holes 49 which penetrate the tubular sidewall in this region about which spiral wrapping takes place.

FIG. 4 is a simplified diagrammatic view showing a single carrier sheet 47 in contact with the perforated portion of a tube 29 and a single leaf 45 associated with it. It should be understood that a plurality of pairs of carrier sheets 47 and associated leaves 45 will be spirally wrapped about the tube 29 to form the element as depicted in FIG. 3. Each leaf 45 is in the form of a membrane envelope that contains a permeate/filtrate sheet 41 and that is open along one side edge. As depicted in FIG. 4, the envelope portion of the leaf is formed from membrane sheets 53a and 53b which sandwich the permeate sheet 51 there between. The sheets 53a, 53b are preferably halves of a folded-over length of membrane 53 with the fold being located in the region adjacent the tube 29 as depicted in FIG. 4. If desired to prevent leakage through the membrane should cracks or fractures occur over time at the location of the fold where bending is severe, a line of adhesive can optionally be provided or reinforcing as disclosed in U.S. Patent No. 5,147,541 can be optionally used.

The membranes can be any semipermeable material, such as RO, NF, UF or MF membranes, all as well known in this art. For example, any of a wide variety of commercially available UF membranes may be used, such as the PES-UF membranes sold by Fluid Systems Corporation. High flow NF and RO membranes are commercially available which are designed to function at pressures of about 200 psig and below, and examples include the SR membranes and ULP membranes marketed by Fluid Systems. However, elements made of MF membranes may be particularly preferred as they will provide separation devices that can produce particularly high flow and high recovery while operating at a relatively low feed pressure. By high flow membrane is meant one which will produce a flux when operated at normal pressure (which is not higher than about 200 psig) of at least about 50 gallons per square foot per day (GFD). By high recovery is meant that a major fraction of the feed will become permeate, i.e. at least about 50%, preferably at least about 90% and more preferably at least about 95%. For example, membranes of the type commercially sold by Celanese Corporation as Celgard, or by Millipore Corporation, as described in U.S. Patent No. 5,032,274, or by W.R. Gore may be used. All of these membranes generally fall within the category of semipermeable membranes and are commonly used in crossflow filtration. The stream

which selectively passes through the membrane is referred to either as the permeate or the filtrate (which terms are used interchangeably herein); the portion of the feed stream that does not penetrate the membrane-lined passageway during its travel spirally inward, and thus reaches the central porous tube 29, is variously referred to as the concentrate or the retentate.

The carrier sheets 47 may be made of any suitable materials as well known in this art that serve a general spacer function, and open mesh materials, such as woven synthetics or cross-extruded polypropylene fabric, e.g. that sold under the trade names Vexar and Naìle, may be used. The use of such passageway-providing permeate sheets 51 is likewise well known in the spirally wound membrane art, and these sheets may be woven or nonwoven polyester sheet material, such as that long available as Tricot polyester.

One method of generally traditional manufacture of spirally wound membrane elements is schematically depicted in FIG. 4. To create such an element 13, a plurality of lengths of Vexar sheeting or other suitable feed/concentrate carrier material 47 are associated with a perforated tube 29 and interleaved with leaves 45 in the form of folded-over microporous membrane material of the type such as Celgard, which is a composite having one surface that is a filtration layer and an opposite surface that is a backing layer. The composite membrane is oriented so that the backing layer is at the interior of the fold and will lie adjacent the permeate sheet 51 that is being sandwiched therebetween. The membrane envelopes are fabricated by the application of lines of adhesive, sometimes referred to as glue lines in the trade, along selected edges of the membranes and the feed/concentrate carrier sheets. In this respect, lines of adhesive 55a are applied along both surfaces, i.e. the inside or permeate-side and the outside or Vexar-side, of what will be the feed-side edge of the membrane material in order to totally seal this one longitudinal edge of the folded sheet of membrane 53. In addition, a transverse line of adhesive 55c is applied across inside surfaces of the two free ends of the folded-over membrane to join them and thus create an elongated rectangular envelope in which the permeate sheet 51 is disposed, which envelope is open along its other longitudinal edge.

As also illustrated in FIG. 4, the lines of adhesive 55a applied to the outside surface of each membrane 53 are thick enough to also fill the feed-side edge of

the carrier sheet, and second lines of adhesive 55b are applied for the full length of the carrier sheet along the opposite or exit-side edge; this creates a liquid-tight seal between each side or longitudinal edge of the carrier sheet 47 and the facing edges of the membrane surfaces of each of the leaves 45 with which it is associated. As can be seen from FIG. 4, the carrier sheet 47 is substantially longer than the envelope 45 so that, when the envelope is entirely spirally wound about the porous tube 29, there is some additional length of the carrier sheet extending beyond the end of the associated leaf by which, as can be seen from FIG. 3, constitutes the annular open mesh section 35. Because the line of adhesive 55b along the exit-side edge of the carrier sheet is of full length, whereas the line of adhesive 55a along the feed-side edge is only as long as the rectangular edge of the envelope, an entrance to the annular region and then to the feed passageways is provided from the plenum 26. Once the winding is complete, this cylindrical subassembly is helically wrapped with imperforate plastic tape 37, as is common in the art, to retain it in tight configuration.

Traditionally, such separation cartridges using spirally wound semipermeable membrane arrangements have been installed in separate tubular pressure vessels which are designed to provide a flow of the liquid being treated axially through the cartridge. Although the spirally wound element 13 having the aforementioned construction could also be used within a traditional pressure vessel where the feed is pumped under pressure into one end and the concentrate is withdrawn from the central tube, the illustrated construction can advantageously be incorporated into a self-contained separation device 11 wherein an adequate pressure vessel is formed integrally with the spiral element. An apparatus 61 for forming such a self-contained separation device 11 is shown in FIG. 5. The apparatus 61 includes a frame 63 which is mounted on a reciprocating carriage so as to reciprocate the directions X and Y as depicted. The reciprocating carriage carries a reservoir of viscous polymeric resin 65. The arrangement is such that a plurality of strands or tows 67 of fibrous material, e.g. fiberglass, are fed from a plurality of spools or creels 69. The apparatus includes a spindle assembly 71 which is designed for rotation in the direction of the arrow shown by drive shaft 73 which is connected by a chuck 75 to the spindle assembly 71.

To prepare for the winding operation, an ATD 21 and a circular seal 23 of square cross-section is mated with each of the dome-shaped heads 17, 19, which are

in turn located in juxtaposition with the ends of the element 13 that is shown in FIG. 2. The standard ATD includes a series of spokes which radiate inward from an outer ring and prevent the spirally wound element from telescoping when axial pressure is applied, as well known in this art. The circular seals 23 guard against liquid under pressure being forced between the ATD and the interior edge of the dome-shaped head. when the subassembly is ready containing the element 13, the heads 17 and 19 and the associated ATDs, it is mounted on the spindle assembly 71 on the pressure vessel winding apparatus 61.

With the arrangement secured, the drive shaft 73 is powered to cause the spindle assembly and the subassembly mounted thereon to rotate about its axis. The fiberglass tows 67 are run through a feed plate 64 leading to the reservoir of resin and then through a squeeze-off bushing 77 which groups the tows into the desired cross-sectional shape to create an array of polymer-impregnated fibrous material that is wound about the rotating cylindrical element 13. The reciprocating carriage is caused to slowly travel in one direction applying a helical wrapping of desired thickness until it reaches one end of the cylindrical element where the head is located and where a polar-wrapping step is carried out before the carriage reciprocates back to the opposite end. State-of-the-art apparatus are commercially available which will wrap strands or tows of fibers polarly about the major portion of each dome-shaped head, as generally depicted in FIG. 1. Such helical-winding and polar-winding steps are repeated a multitude of times so as to build up a pressure vessel sidewall of the desired thickness and strength that will withstand the internal pressures that will be employed during the separation operation. For example, from about 5 to 15 courses of helical wrapping may be carried out using fiberglass tows impregnated with a resin which is heat-curable at, for example, 200°C, e.g. an epoxy, a polyester, or a polyurethane resin. Such thermally curable resins are well known in the art, and a variety of catalysts can be employed to effect the curing. If desired, curing can be carried out at room temperature over a longer period, i.e. a matter of days. Once curing is complete, the separation device 11 is finished by adding the suitable plumbing attachments for the feed inlet and the filtrate outlet, and it is ready for use at pressures as high as about 200 psig.

As previously indicated, a variety of different membranes can be employed and generally the character of the membrane and the characteristics of the

solution being treated will determine the feed pressure that will be used, and thus the pressure which the *in-situ*-formed pressure vessel will be required to withstand. As previously indicated, this design is considered to be particularly advantageous for use in separation devices operating at relatively low pressures where high flow, high recovery microfiltration is to be carried out; thus, microfiltration membranes of the composite type will frequently be employed to construct the spirally-wound leaves. The strands or tows of synthetic fibers or filaments may be any suitable synthetic material, even carbon fibers; however, fiberglass tows are frequently used, as such will provide adequate tensile strength for devices to be used for microfiltration separations. Alternatively, other well known synthetic fibers made of certain polyesters or Kevlar or the like or carbon fibers may be used, depending upon the desired ultimate structural strength. Likewise, although winding as to create such tubular structures is frequently carried out using a plurality of independent strands or tows which are then gathered following impregnation with the polymeric resin material, elongated strips of woven or nonwoven fibrous material or the like may alternatively be used, which would be likewise fed through a reservoir of viscous polymeric resin.

To test the design of such a spirally wound element, a demonstration four-inch diameter element is rolled having an axial length of 14 inches. Four leaves 45 are used and associated with four separate carrier sheets 47. The membranes 53 are commercially available composite polytetrafluoroethylene MF membranes. Tricot woven sheeting having a nominal thickness of about 20 mil is used as the permeate sheet material 51 to provide the filtrate or permeate passageways, and the carrier sheets 47 are cross-extruded polypropylene having a thickness of about 0.046 inch sold by Nalle Plastics.

At a feed pressure of about 34 psig, the spiral wound element produces permeate at a flow rate of about 5.15 gallons per minute and concentrate at a flow rate of about 0.25 gallons per minute, thus evidencing high flow and high recovery properties which would be suitable for operation on an aqueous feed containing from about 0.1% to about 5% suspended solids. This performance illustrates that the designs of the element would be excellently suited for use as a final polishing treatment step for a municipal water treatment plant where biological purification would be effected along with removal of suspended fine solids. In the latter respect, this design significantly

improves backwashing compared to traditional spiral wound crossflow filtration elements.

Although the invention has been described with regard to certain preferred embodiments which constitute the best mode presently known to the inventors, it should be understood that various changes and modifications as would be obvious to those having ordinary skill in the art may be made without departing from the scope of this invention which is defined in the claims appended hereto. For example, although the spiral element fabrication can be carried out in the traditional manner as illustrated in FIG. 4, this particular construction also lends itself to an alternative, more automated and simpler fabrication method. For example, the spiral wound element can be rolled while applying only the transverse strips of adhesive 55c along the radially outward edge of each envelope. The rolled and wrapped element is then aligned with its axis vertical and positioned in a suitable jig that would accommodate the protruding imperforate portion of the concentrate outlet tube 29. A measured amount of a relatively low viscosity, polymeric potting material, such as a thermosetting epoxy, polyester or polyurethane resin, could be fed under some pressure to the end face of the spiral element so that it would penetrate into the open mesh carrier sheet material 47 but would only slowly wick into the thinner, denser, Tricot permeate sheets 51. As a result, this potting material would flow upward into the Vexar or Nalle carrier layers 47 to a much greater height than it would wick into the Tricot fabric 51. As a result, when the resin cures, it totally seals the entire axial end of the spiral-wound element. A trimming operation is then carried out so as to eliminate the end of the element to a distance exceeding the height to which the resin would wick into the Tricot fabric. As a result of such a trimming operation, a spiral exit passageway is opened along the edge of the envelope for the entire length of the permeate flow passageway, while the edge of the carrier material including the circumferential annular feed region 35 remains blocked as a result of the tight seal between the impregnated edge region of the carrier material and the surfaces of the adjacent membranes.

This potting process is then repeated to seal the opposite end of the element after blocking the radially outer annular region 35 by the disposition of a thin layer of wax gasket material or the like along the outer 12 inches or so of the open mesh material 47 that will block penetration of the viscous polymeric resin in this region. The

resin may then be caused to fill the edge of each carrier sheet to a greater depth than the width of the wax sealing layer. Thereafter, following curing of the resin, either trimming of the axial end of the element or removal of the wax by heating will leave the entire feed end of the cylindrical element sealed with the exception of the outer annular region 35, which will receive flow of the feed liquid from the feed plenum 26 and channel it to the plurality of carrier sheets 47.

Although microfiltration applications have generally been stressed in the foregoing description, the invention is similarly felt to have valuable uses in the field of UF and also for treatments at relatively low pressures using high flow NF or RO membranes.

Particular features of the invention are emphasized in the claims which follow.

WHAT IS CLAIMED IS:

1. A spirally wound filtration device which comprises: a plurality of leaves and feed/concentrate carrier sheets wound in spiral configuration about a central elongated liquid concentrate outlet to form a generally cylindrical element, means surrounding said spirally wound element for maintaining same in generally cylindrical condition, feed inlet means for feeding liquid to be treated to a region near a radially outer surface region of said cylindrical element, first exit means for removing concentrate from said central elongated outlet, second exit means for removing liquid permeate from one axial end of said element, each of said leaves including a permeate sheet sandwiched between two microporous membrane sheets which membrane sheets are interconnected at the spirally inner end thereof, along one side edge and at the spirally outer end thereof so as to form a generally rectangular envelope about said permeate sheet from which liquid may exit via the open other side edge, which envelope is spirally wound about said central outlet so that said open side edge is located along one axial end of said element, and a feed/concentrate carrier sheet associated with each of said membrane sheets so as to provide a flow passageway for the supply of liquid to be treated to each exterior surface of each of said envelopes, each said feed/concentrate carrier sheet being sealed along both side edges to adjacent side edges of said associated envelopes, at each axial end of said element, so that the only entrance to each said flow passageway is at the spirally outer end thereof and the only exit therefrom is at the spirally inner end thereof where there is communication between said flow passageway and said central elongated outlet, communication between said flow passageway and said central elongated outlet, whereby high flow and high recovery treatment of liquid at relatively low feed pressure is possible using the device.

2. The device according to claim 1 wherein said microporous membrane is asymmetric having a filtration layer portion at the exterior surface of said envelope and a backing layer portion at the interior surface thereof adjacent said permeate sheet.

3. The device according to claim 2 wherein said microporous membrane is a UF membrane.

4. The device according to claim 2 wherein said microporous membrane is a high flow NF or RO membrane.

5. The device according to claim 1 wherein a circumferential region of open mesh material surrounds said spirally wound leaves and is in fluid connection with each of said feed/concentrate carrier sheets to facilitate the supply of liquid thereto.

6. The device according to claim 5 wherein one said feed/concentrate carrier sheet is located between each two adjacent leaves, with its spirally outer end being in liquid communication with said outer region and wherein said envelope is formed by a single piece of said membrane which is an MF membrane that is folded upon itself to create said two membrane sheets, with the fold located at the spirally inner edge thereof and with the spirally outer edges of said two membrane sheets being sealed to each other.

7. The device according to claim 1 wherein said side edges of said spirally wound feed/concentrate carrier sheets, at the axial ends of said element, are sealed with materials which creates longitudinal side boundaries of said flow passageways and also bonds same to said associated envelope surfaces.

8. The device according to claim 1 wherein pressure-tight heads are located at opposite axial ends of said element and united thereto by a fiber-reinforced polymeric shell.

9. The device according to claim 8 wherein one of said heads contains said concentrate exit means and said permeate exit means and said permeate envelopes open toward said one head and wherein said feed inlet means is located in the other of said heads and communicates with said circumferential region.

10. A method of high flow, high recovery filtration of liquids, which method comprises: winding a plurality of leaves and feed/concentrate carrier sheets in spiral configuration about a central elongated liquid concentrate outlet to form a generally

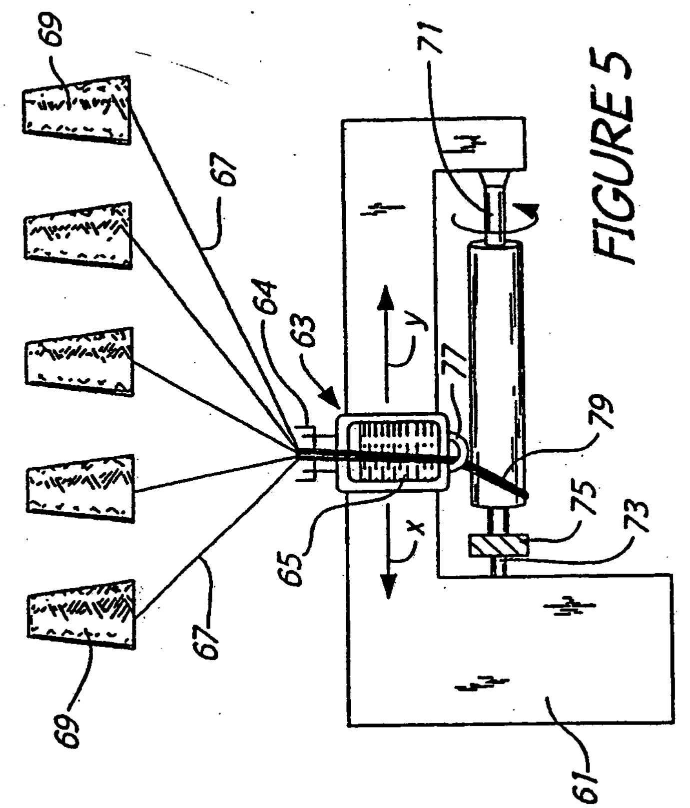

FIGURE 5

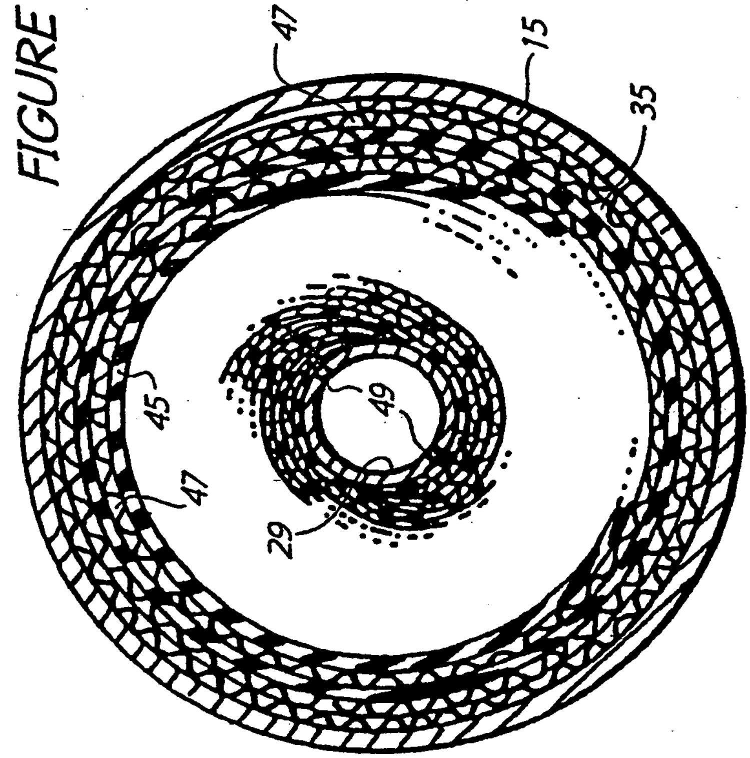

FIGURE 3

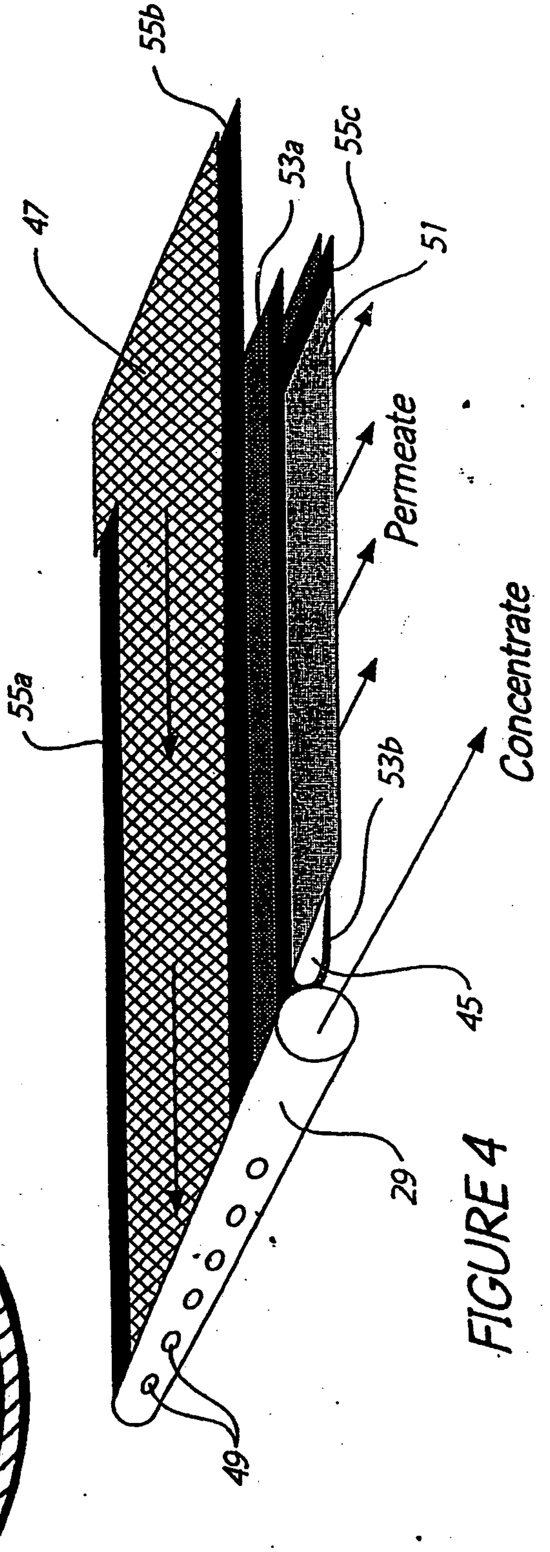

FIGURE 4